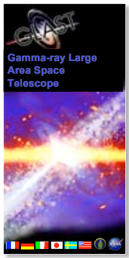
Prospects for Pulsar Studies with the GLAST Large Area Telescope



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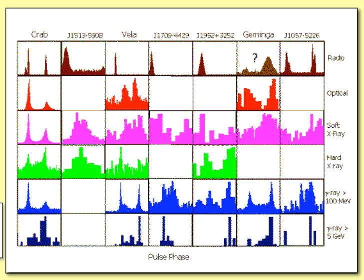
Abstract

The Large Area Telescope (LAT) on the Gamma-ray Large Area Space Telescope (GLAST) will have unprecedented sensitivity and energy resolution for gamma-rays in the range of 30 MeV to 300 GeV. GLAST is therefore expected to provide major advances in the understanding of high-energy emission from rotation-powered pulsars. As the only presently known galactic GeV source class, pulsars will be one of the most important sources for study with GLAST. The main science goals of the LAT for pulsar studies include an increase in the number of detected radio-loud and radio-quiet gamma-ray pulsars, including millisecond pulsars, giving much better statistics for elucidating population characteristics, measurement of the high-energy spectrum and the shape of spectral cutoffs and determining pulse profiles for a variety of pulsars of different ages. Further, measurement of phase-resolved spectra and energy dependent pulse profiles of the brighter pulsars should allow detailed tests of magnetospheric particle acceleration and radiation mechanisms, by comparing data with theoretical models that have been developed. Additionally, the LAT will have the sensitivity to allow blind pulsation searches of nearly all unidentified EGRET sources, to possibly uncover more radio-quiet Geminga-like pulsars.

Gamma-Ray Pulsars

The EGRET telescope on the Compton Gamma-Ray Observatory (CGRO) detected 6 pulsars with high significance, as well as 5 candidate detections (Kanbach 2006). The spectral power for 5 of these pulsars (with the exception being the Crab) peaks at an energy above 100 MeV. At least 3 (Vela, Geminga and B1951+32) show evidence for high energy spectral cutoffs between 2 and 50 GeV. The pulse profiles for energies > 100 MeV are varied but wide double-peaked morphology is dominant.



Multiwavelength pulse profiles of γ-ray pulsars detected by CGRO

Fundamental questions:

- Where and how are particles accelerated to at least 1 TeV?
- How do the particles interact? With what?
- Is it the same for all pulsars?
- How does the complex environment (frame dragging, aberration, strong magnetic and electric fields, high currents) produce the observed radiation patterns?

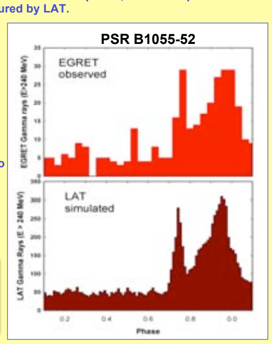
With more than an order of magnitude increase in sensitivity, the GLAST LAT should provide a large statistical sample of profiles and viewing angles to probe the geometry of the emission.

Pulse Profiles

With larger numbers of photons detected for each pulsar, much sharper and well-defined pulse profiles will be measured by LAT.

Is the emission away from the pulse associated with the source (as predicted by the slot gap) or not (predicted by outer gap)?

How are the pulse shapes, peak separation, and relationship to pulses seen at other wavelengths explained in different models?



Top: Profile of PSR B1055-52 observed by EGRET.

Bottom: Simulation of profile LAT might observe in 2 years, with a shape estimated from EGRET profile.

Courtesy D. Thompson

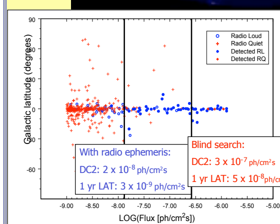
Multiwavelength Support

Pulsars undergo rapid and often noisy spin down. In order to conduct accurate γ-ray pulsation searches in LAT data for the known radio, optical and X-ray pulsars, near-simultaneous ephemerides are needed. Periodic timing of about 200 radio pulsars will be carried out during the GLAST mission by several large radio observatories, including Jodrell Bank in England, the Parkes telescope in Australia, and the Nancay telescope in France. Priority for timing will be based on a rank ordering in $\dot{E}_{SD}^{1/2} / D^2$. In addition, X-ray timing solutions will be obtained for a smaller sample of pulsars using X-ray telescopes such as RXTE.

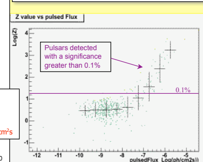
Pulsed Emission Sensitivity

Estimates of the sensitivity of the LAT to pulsed emission come from the recent Data Challenge II (DC2), in which populations of gamma-ray sources of different classes, including pulsars, were simulated with realistic sky background for 55 days.

Map of sources and diffuse emission in the DC2 sky in galactic coordinates. Green circles are the locations of EGRET pulsars.



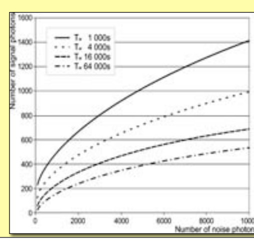
Galactic latitude vs. phase-averaged flux of radio loud and radio quiet pulsars simulated for the DC2 sky, with estimated detection thresholds.



Log of Z-test statistic vs. phase-averaged flux for the DC2 radio-loud pulsars. *(Courtesy A. Caliandro)*

Blind Pulsation Searches

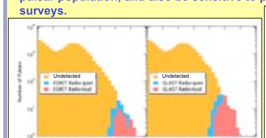
Search for pulsations will be possible for bright sources without use of a known ephemeris. Blind search algorithms are being developed and tested with favorable results.



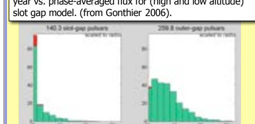
Simulation of time-differencing blind pulsation search algorithm (Ziegler et al. 2006), showing the number of source photons required for a 95% detection vs. the number of noise photons, for different maximum time difference T_W. (Courtesy *M. Ziegler)*

Expected Population

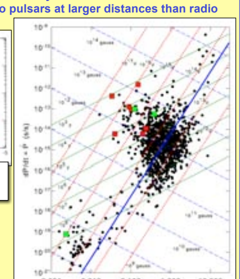
How many pulsars do we expect to detect with GLAST? Population synthesis studies predict that in 1 year LAT may detect several hundred γ-ray pulsars (Gonthier et al. 2004, Jiang & Zhang 2006). The relative numbers of radio-loud and radio-quiet γ-ray pulsars are very model-sensitive, with polar cap models predicting roughly equal numbers while outer gap models predict a much larger number of radio-quiet pulsars. The LAT sensitivity will reach the bulk of the radio pulsar population, and also be sensitive to pulsars at larger distances than radio surveys.



Number of γ-ray pulsars detected by EGRET and LAT in 1 year vs. phase-averaged flux for (high and low altitude) slot gap model. (from Gonthier 2006).



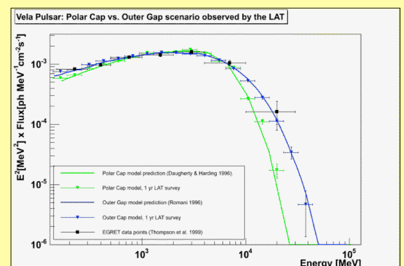
Simulated distance distribution of γ-ray pulsars detected by LAT in 1 year for high-altitude slot gap and outer gap models. (from Harding, Grenier & Gonthier 2006).



Period vs. period derivative distribution of radio (black dots) and γ-ray (red – high, green-low confidence) pulsars. Blue line indicates the potential sensitivity limit of LAT (Thompson 2006).

Spectral Cutoffs

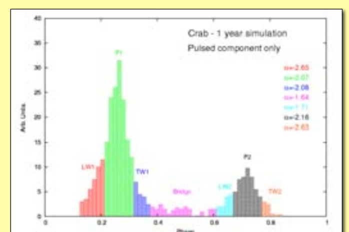
Spectral measurements of the brightest pulsars with greater energy range (30 – 300 GeV) and resolution will define the shape of the high-energy cutoffs well enough to discriminate between the predictions of different emission models. In polar cap models where high-energy emission originates near the neutron star, a very sharp cutoff is caused by one-photon pair production absorption in the strong magnetic field. In outer gap models where the emission originates in the outer magnetosphere, a more gradual cutoff is caused by radiation reaction of the emitting particles.

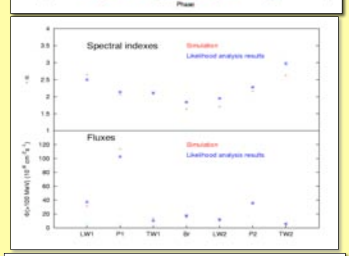


Courtesy M. Razzano

Phase Resolved Spectroscopy

Measurement of spectral properties as a function of pulse phase will provide an important diagnostic of emission physics. Better photon statistics for the brighter pulsars will enable finer phase resolution than was possible with EGRET.





One year LAT simulation of the Crab pulsar, including sky background, and spectral indices in various phase ranges. Top: input profile Bottom: results from a likelihood analysis for the spectral index and flux in the same phase ranges. *(Courtesy T. Reposeur)*

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